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Lyman-Alpha Photographs of the Sun's Disk

The following report is based on material supplied by J. Dewitt Purcell and Richard Tousey, of the Naval Research Laboratory.

The sun is commonly thought of as a smooth yellowish disk occasionally marred by small dark blemishes called sunspots. Actually, the sun has as many different faces as astronomers can find wave lengths of radiation in which to observe it. In the red light of excited hydrogen, it shows fuzzy, lacy bright areas (plages) and a turbulent, grainy surface. In calcium violet light it takes on a mottled surface appearance that has been likened to the skin of an orange, with the plage regions showing even brighter. Recently, for the first time, highly detailed photographs of the entire sun were taken in the light of the Lyman-alpha line of hydrogen. (An earlier photograph, obtained by W. A. Rense from a rocket flown in 1956, suggested strongly that Lyman-alpha radiation was not emitted uniformly by the surface of the sun. However, the image was faint and lacked sufficient resolution to outline the edge of the solar disk or to make possible a detailed correlation with photographs at other wave lengths.)

Lyman-alpha light is in the extreme ultraviolet region of the spectrum, midway between visible light and X-rays. It originates in regions of the solar atmosphere 4000–6000 mi above the sun's surface. When large amounts are absorbed by the D-region of the earth's ionosphere, this radiation may have a powerful effect on radio communications, causing disruption or changing the quality of transmission on many short-wave radio wave lengths.

The photographs were taken from an altitude of 123 mi by a small, specially-constructed solar observatory in the nose

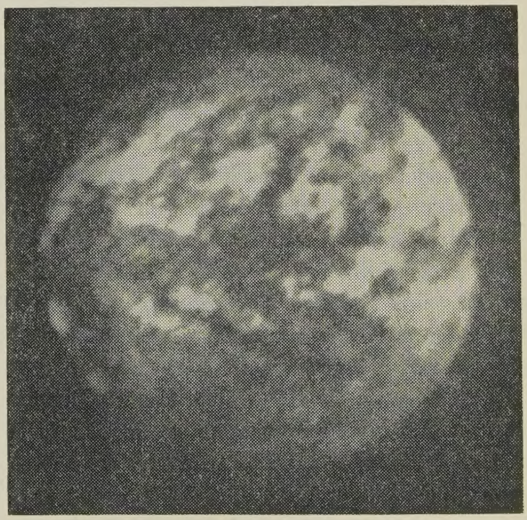

Fig. 1. *Rocket Photograph of Sun in Light of Lyman-alpha Radiation. Bright areas are high-temperature, Lyman-alpha-emitting gas clouds high in the solar atmosphere. Darker areas are cooler and at lower levels. Official US Navy photograph.*

of an Aerobee-Hi rocket launched from White Sands, New Mexico, on March 13, 1959. The experiment was designed and the launching conducted by the Naval Research Laboratory as part of the IGY Solar Activity Program.

The Experiment

Although the sun has in the past been photographed frequently in light of various other wave lengths, highly detailed photographs have never before been obtained in the light of Lyman-alpha, most of which is absorbed in the D-region, 40–55 mi above the earth's surface. The photographs, 60 of which were obtained within a period of about a minute, show great, bright, irregular clouds of hydrogen gas high in the solar atmosphere. The clouds cover about ⅛ of the disk, mostly in the sun's northern hemisphere, and have temperatures in excess of 6000°C. (See Fig. 1.)

During the rocket flight on which these Lyman-alpha photographs of the sun were made, hydrogen red line, and calcium K line photographs were also being made from the ground at the Mount Wilson Observatory in California, the McMath-Hulbert Observatory in Michigan, the Air Force Observatory at Sacramento Peak in New Mexico, and at NRL in Washington. Comparison of the solar phenomena mapped at these three widely-separated wave lengths is expected to throw new light on the process by which solar energy released inside the sun by nuclear reactions reaches the surface and escapes.

The new Lyman-alpha photographs show the solar weather pattern at the highest level in the solar atmosphere as yet studied over the entire surface of the sun. Calcium K line photographs map the sun's atmosphere farther down into the interior (from the surface to a height of 4000 mi), and photographs in the red line of hydrogen show the pattern still lower in the atmosphere (surface to 200 mi). Thus, photographs at these three levels, when analyzed together, give a sort of three-dimensional picture of the processes taking place in th sun's atmosphere.

It is apparent that the sun is strikingl stormy when viewed by the extreme ultra violet light of hydrogen. The same brigh disturbed areas are present also in th photographs taken from the earth's surface but they are smaller and not as conspicuous The pattern appears to become coarser a higher levels. Though in part, perhaps ascribable to instrument effects, this agree with the concept of ascending columns o turbulent gas, spreading, combining, an merging as they stream out of the sun Eventually, traces of these gases reach th earth. Occasionally, during periods of grea solar activity, they produce auroras an magnetic storms and disrupt radio com munications.

Instrumentation

The spectrographic camera with whic these extreme ultraviolet photographs wer obtained was the result of four years o development at the Naval Research Labora tory. Since Lyman-alpha radiation i strongly absorbed by all materials, lense could not be used and it was necessary t construct the entire camera with mirror These were not ordinary mirrors, howeve but diffraction gratings, mirror surface ruled with 15,000 lines to the inch. Thes rulings cause the intense visible light fro the sun to be thrown out of the camera leaving only the monochromatic Lyman alpha radiation to form the solar image.

Ordinary film cannot be used to photo graph this image because the gelatin binder in the emulsion absorbs the extrem ultraviolet radiation before it can reac the sensitive silver-halide grains. A speci film containing almost no gelatine must b used. This film is very fragile and care mus be taken not to touch the surface or th image will be wiped off.

Once the equipment is in flight, it is sti a difficult problem to ensure taking goo pictures because the rocket's flight path certain to be unstable—rolling, pitching, an

yawing. Precise pointing is essential, as it is to any astronomical telescope. To keep the entire instrument pointed at the sun, a complicated servo system, constructed by physicists at the University of Colorado, was employed. This control system scrutinizes the sun with photoelectric eyes, which feed back into the servo-motors signals telling them which way to correct the pointing of the camera.

The spectrograph used weighed about 35 lbs and the entire payload about 250 lbs.

Conclusions

With these refined techniques, evidences of weather in different parts of the solar atmosphere may be seen and attempts made to correlate the more violent changes in solar weather with terrestrial ionospheric weather and, possibly, with local weather. It is known that solar changes observed with visible light are only indirect indicators of what is happening in the more energetic, invisible ultraviolet and X-ray emissions. Photography of the sun in wave lengths of these powerful short-wave radiations makes possible a tremendous advance toward understanding the relationship between solar activity and its terrestrial consequences.

Lyman-alpha pictures such as those obtained on the March 13 rocket flight show that the radiation is emitted from spots and patches over the solar surface. This knowledge may help us to understand the reasons for the wide range of variations and the rapid changes in quality of radio propagation.

Eventually, such rocket astronomy techniques, leading to the discovery of phenomena forbidden to earth-bound astronomers, may permit routine photography of the sun in the most important short-wave radiations, providing daily solar weather reports for predictions of terrestrial responses.

Studies of Solar Flares and Flare-Associated Terrestrial Phenomena

The following report was prepared by Mary L. Andrews of the High Altitude Observatory, University of Colorado, Boulder, Colorado.

The IGY Solar Activity Program at participating solar observatories in the United States has included studies in basic solar physics and a warning service for upper-atmosphere scientists. The solar physics studies are concerned with physical and chemical properties, processes, and structure of the sun. The warning service (see World Days Report, this issue) is designed to give advance notice for observation of possible magnetic and ionospheric disturbances, and other solar-terrestrial effects, when solar outbreaks have been observed.

One of the major research interests of the High Altitude Observatory of the University of Colorado during the IGY has been the study of solar and terrestrial phenomena associated with flares. Such studies aim toward a better understanding of solar flares themselves as well as of their effects on the ionosphere—the electrically-charged, or ion-

ized, region of the earth's atmosphere. Although flares apparently are the most important of solar events affecting the earth, they are probably the least understood. There is no generally accepted theory of their origin, of the source of the energy they release, or of the precise nature of the emissions from them that so profoundly influence the earth's outer atmosphere.

The Physics of Flares and Related Phenomena

Flares are usually observable only in certain light wave lengths originating in the chromosphere (the lowest level of the solar atmosphere), such as the light of ionized hydrogen and calcium. To an observer viewing the sun through a filter that restricts the light to one of these wave lengths, the flare appears as a sudden brightening of a spot on the disk or limb (outer edge). The typical flare brightens to its maximum intensity in a few minutes then fades gradually in about an hour.

Most flares appear in the bright plage, or disturbed, area surrounding a sunspot group. When seen on the limb, filamented coronal structure is usually seen to be associated with such active regions, often at temperatures considerably hotter than the surrounding coronal gas. (The corona is above the chromosphere in the sun's atmosphere.) Out of these active regions, loop-like prominences, or solar gas clouds, condense. In fact, the tightly-curved loop prominences seen associated with flares sometimes appear to be the flares themselves.

H. Zirin and E. Tandberg-Hanssen of HAO undertook detailed study of the different physical conditions in two types of flare-connected phenomena—loop prominences and surges. (Surges, highly-luminous jets of solar gas rising to heights of 100,000 km or more, may or may not accompany flares; the largest, however, are associated with flares. Surges last about 20 min.) To avoid the difficulties of interpreting the spectra of flares and prominences seen against the background radiation of the disk, the investigators worked with spectra of these phenomena photographed above the limb.

Two bright, flare-like loop prominences appeared on the limb on November 12 and 22, 1956. G. W. Curtis and K. Watson obtained spectra showing hydrogen, neutral helium, and ionized helium lines. From an analysis of these observations, Zirin and Tandberg-Hanssen concluded that the loop prominences have different temperature regions, with ionized helium lines coming from a much hotter region (approximately 100,000°K) than either the neutral helium or hydrogen emissions.[1]

On December 18, 1956, Watson procured spectra of an intense limb flare condensing out of the corona in the form of a loop prominence. There was strong continuous emission from the flare, due to electron scattering, and strong coronal emission in the yellow line at 5694Å and the blue line at 4086Å, from CaXIII. From the behavior of the two coronal lines, Zirin confirmed earlier identification of the yellow line as emission from CaXV.[2]

On December 19, 1956, a bright loop prominence and intense surges appeared at different places on the limb. Watson's spectra, showing both hydrogen and helium as well as the spectrum lines of metals, enabled Tandberg-Hanssen to extend the previous study of temperature variation within loop prominences and to compare these with temperatures in the surges.

The metal lines in both types of phenomena apparently came from regions different from those responsible for the helium and hydrogen lines. The loop prominence was intimately connected with the corona, while the surges welled up from below. The line profiles for the loop broad

[1] H. Zirin and E. Tandberg-Hanssen, "Physical Conditions in Limb Flares and Active Prominences I. The Loop Prominences of 12 Nov. and 22 Nov. 1956." Astrophysical Journal, March 1959.

[2] H. Zirin, "Physical Conditions in Limb Flares and Active Prominences II. A Remarkable Limb Flare, 18 Dec. 1956." Astrophysical Journal, March 1959.

ened toward the top, indicating increasing temperatures away from the limb. Line profiles for the surges, on the other hand, suggested decreasing temperatures as the material shot farther outward from the solar surface.[3]

Solar-Terrestrial Effects

Although ionospheric disturbances, geomagnetic variations, and auroras frequently follow flares, only a few of the solar emissions, both radiational and corpuscular, which enter the earth's atmosphere have as yet been identified. Similarly, the physical mechanisms in the earth's atmosphere that produce these terrestrial effects still present many unsolved problems.

Radio-wave Absorption: J. W. Warwick and H. Zirin are attempting to determine the nature of the flare radiation that causes sudden ionospheric disturbances. As a first step, they studied records of flare-induced ionospheric radio-wave absorption obtained with the IGY SCNA (sudden cosmic-noise absorption) recorder in Boulder.

Assuming that the ionizing flare radiation was Lyman alpha and making certain other assumptions about the response of the atmosphere to this ionizing radiation, Warwick and Zirin analyzed the absorption data for the earth's atmosphere associated with five flares. (A recent rocket finding suggested that ionizing radiation occurring during a flare was X-rays [*Bulletin No. 19*]. Warwick and Zirin note, however, that the beginning of a flare may be missed in a rocket experiment as the rocket is not usually launched until after the flare has begun. They suggest that the sudden cosmic noise absorption accompanying a flare may result from a Lyman-alpha burst at the very start of the flare.) In the analysis, they found it necessary to use a very large value for the effective recombination coefficient to fit the observed absorption as a function of time

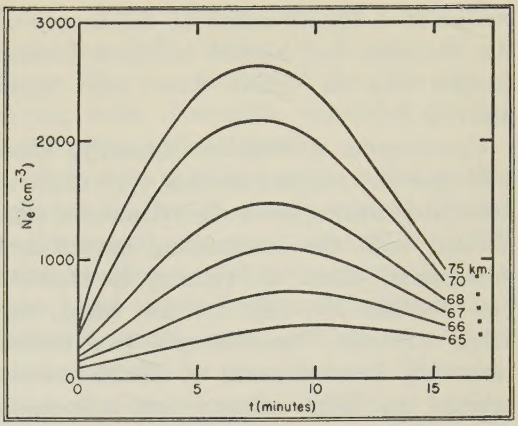

Fig. 2. *Electron Densities at Particular Heights, as a Function of Time, from the SCNA Record of February 6, 1957:1733 UT. A recombination coefficient of 5 × 10^{-6} is indicated. The plot shows the lag in response by the lowest ionospheric levels following an impulse of radiation at some earlier time. The symbol N_e represents the electron density.*

throughout the flare; the best fit was obtained by a coefficient of 5×10^{-6} cm^3/sec. With this value they calculated electron densities as a function of time and height (see Fig. 2).

(The great increase of ultraviolet radiation resulting from a flare causes a corresponding increase of ionization in the D-region, the lowest region of the ionosphere, owing to loss of electrons by upper-air molecules. As the flare diminishes in intensity, recombination of the free electrons with ionized air molecules takes place. The effective recombination coefficient describes the rate at which free electrons are removed from the atmosphere in this way, and through certain other processes.)

Although this analysis was predicated on a simple theory of formation of the D-region, the results would probably hold also for more complex theories, at least for those in which the ionizing flux varies uniformly at all wave lengths as a function of time. The principal conclusion was that the D-region remains essentially in radiative equilibrium, with the rate of ionization balancing the rate of recombination. This conclusion

[3] E. Tandberg-Hanssen, "Physical Conditions in Limb Flares and Active Prominences of 19 Dec. 1956," (to be published in Astrophysical Journal, July 1959).

results in a simplification of the theory of the D-region and should facilitate further comparisons of radio data with solar activity.[4]

Cosmic-noise Absorption: Recently, Warwick has also studied another type of flare-associated atmospheric disturbance in connection with the outstanding aurora and geomagnetic storm of February 10–11, 1958 (see *Bulletin No. 18*). On that night, the High Altitude Observatory's two corner reflectors, located north of Boulder, were trained to follow the cosmic-radio-noise source Cygnus A as it circled across the low northern sky. Rigged as an interferometer, the reflectors record cosmic-noise absorption at 18 mc.

From antenna records of signal strength during the night of February 10–11, Warwick found an area of 100% absorption to the northeast and about 10° above the horizon. This area corresponded with the region in which the auroral arc would presumably have been visible had the night been clear in Boulder. This was also the area for which S. Matsushita postulated intense electric currents (discussed below), and in which J. R. Winckler and others observed X-radiation.

The detailed time variations of the absorbing region found by Warwick followed closely the time variations of absorption over the entire sky as measured by the Boulder SCNA recorder. These observations indicate that the ionizing particles ultimately responsible for the absorbing region during the February 10–11 event simultaneously affected an enormous region of North America.[5]

Magnetic Variations: S. Matsushita studied records of magnetic variations for the February 10–11 disturbance from a network of seven closely-spaced stations in the central United States and from the observing stations at Fredericksburg, Va., and Tucson, Ariz. This close network was established for the IGY by the Coast and Geodetic Survey (see *Bulletins 3* and *18*).

Matsushita found that during magnetic

[4] J. W. Warwick and H. Zirin, Scientific Report No. 9, ARDC Contract AF19(604) 1491, January 1958.

[5] J. Warwick, Science *127*, 1047, 1958

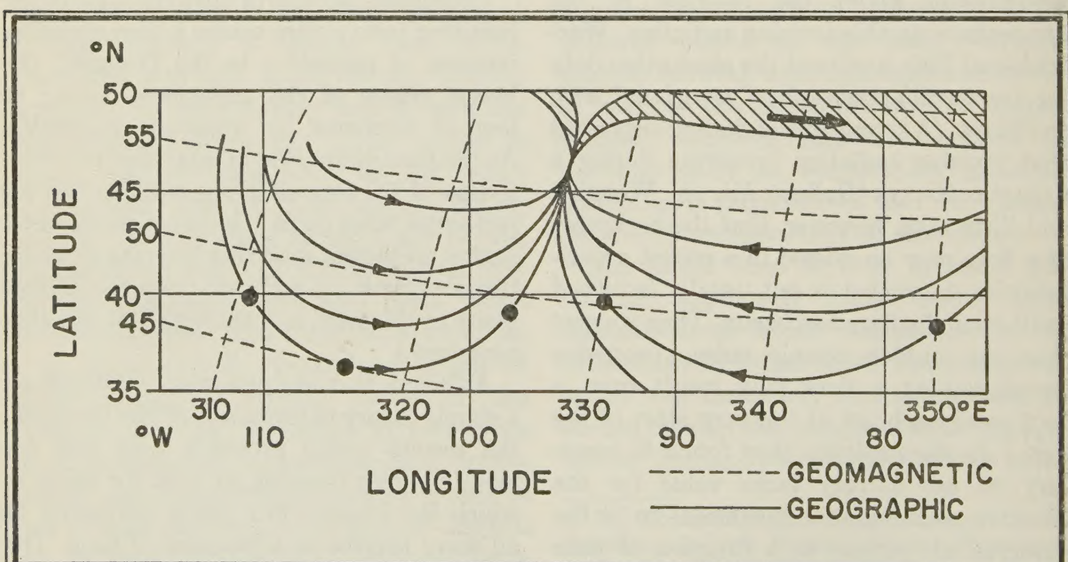

Fig. 3. *Current Pattern Suggested by Geomagnetic and Ionospheric Observations During the February 10–11, 1958 Magnetic Storm. The hatched area at the top represents the strong auroral current at 100 km. The five stations shown by the large black dots are, from west to east: Price, Utah; Espanola, New Mexico; Beloit, Kansas; Carrollton, Missouri; and Fredericksburg, Virginia.*

disturbances the variations of the earth's magnetic field at the seven stations are usually quite similar, although on some occasions there have been significant differences. For the February 10–11 storm, the stations at Carrollton, Mo., and Fredericksburg recorded negative bay-shaped variations in the horizontal component of the field, while the western stations showed positive variations in the same component. At the intermediate station in Beloit, Kan., the horizontal variation was first negative and then positive.

Ionograms, photographic records relating the heights of radio-signal echoes to the different radio frequencies, were obtained with vertical incidence ionosondes at Washington, D. C. (Ft. Belvoir, Va.), Boulder, Colo., White Sands, N. M., and San Francisco, Calif., during the February 10–11 storm. The records showed that the area of strong radio absorption expanded toward lower geomagnetic latitudes.

Matsushita therefore suggests that on this occasion the strong electric current flowing in the auroral zone at a height of about 100 km moved to a much lower magnetic latitude than usual. Leaks from this current at low latitudes could have created a current pattern similar to that shown in Figure 3, which fits the observed variations at the different stations.[6]

[6] S. Matsushita, High Altitude Observatory Solar Research Memorandum, No. 119, November 1958.

Antarctic Snow Stratigraphy

This report is based on part of a paper presented by William W. Vickers, Arctic Institute of North America, at the IGY Symposium during the 125th Meeting of the American Association for the Advancement of Science, Washington, D. C., December 29–30, 1958.

In an effort to determine the pattern and rate of snow accumulation in the Antarctic, layering visible in the walls of pits dug in the snow at several IGY scientific stations was studied.

This report describes some results of studies performed by William W. Vickers under an IGY contract administered by the Arctic Institute of North America. (Related investigations of wind transport of snow were reported in *Bulletin No. 22.*)

Accumulation and Snow Stratigraphy

For determinations of the volume of Antarctic ice, seismic methods are employed to obtain the important depth dimension. To determine the *change* in volume, however, several simultaneous processes must be examined—mass dissipation by heat, calving of icebergs along the coast, wind transport of snow, and the annual snow accumulation. Studies of snow stratigraphy, or layering, are an important part of the snow accumulation investigations.

Layering exists in the walls of snow pits much as earth strata in a large road-cut. Summer and winter snow layers show different characteristics, which, when closely examined, enable the years to be distinguished. This type of investigation was first carried out successfully in Greenland. However, there was some doubt that the method could be readily applied in Antarctica where very low temperatures over most of the continent throughout the year do not allow easily identified summer-melt characteristics to form.

In order to verify the method for Ant-

arctica, a 23-ft pit was excavated at the site of Admiral Byrd's 1939 camp, Little America III. Byrd's "snow cruiser," a bus-like vehicle intended for use on this earlier expedition, was found resting on the 1939–40 summer snow layer, and could, therefore, serve as a bench mark for stratigraphic studies down to this level. The snow-stratigraphy interpretations made in this pit were found to be in error by one year for this interval of 18 years. (See Fig. 4.)

The stratigraphy recorded in Antarctic snow pits is now being analyzed at the Ohio State University Glaciological Data Reduction Center, under the direction of Richard P. Goldthwait. Annual accumulation for areas thus far reported is as follows:

Station	*Accumulation (cm)*	*Source*
Byrd	14	V. H. Anderson
Ellsworth	20	P. T. Walker
Little America III	16.2	W. W. Vickers
Little America V	15.5	W. W. Vickers
Victoria Plateau	16.3	W. W. Vickers
Wilkes	14	R. L. Cameron

The above figures represent 10-year averages, except for the Little America III figure, which represents 18 years. They also represent large areas, which vary considerably in detail.

Snow Metamorphism

To learn more about the metamorphism of snow—the alterations of the crystals resulting from an assortment of physical phenomena, some of which are referred to below—control pits were dug at IGY Little America Station; these were re-excavated periodically to correlate snow metamorphism with change of season. Winter snow was characteristically fine-grained, closely-packed, and in relatively thick layers. Summer snow was coarse-grained, loosely-packed, and thin-layered.

Melt Crusts: At relatively-warm IGY Little America Station, melt crusts about 1 cm thick were formed, as well as other obvious melt features. However, the origin of milky 2-mm crusts, found not only at Little America Station but also on the very high, very cold Victoria Plateau, is less certain. Most observers felt that these resulted either from contact-freezing, at the surface, of super-cooled rain or mist, or, perhaps, from insolation (direct radiation from the sun).

According to P. A. Shumskii, chief Soviet glaciologist in the Antarctic, these 2-mm crusts may be formed by the sun's rays penetrating vertically-oriented snow crystals along the c-axis (the vertical axis), causing melting within and at the base of the crystal—a "greenhouse" effect. Examination of these milky crusts (with a hand lens) on the Victoria Plateau showed the bottom side of the crusts to be straight and regular, possibly from the melting and joining of crystal bases. The tops were serrated, as might be expected in a group of hexagonal crystals. This was in keeping with Shumskii's views, but if basal melting does occur, vapor figures (bubble-like cavities formed within an ice crystal by the change in volume resulting from internal melting) should be found inside some of the crystals. None were observed.

This greenhouse theory, if later proved correct, would provide an excellent summer snow indicator for the vast Antarctic highland area, where the usual summer melting phenomena are nonexistent. These crusts could not form in the absence of sun during the long polar night, whereas the summer surface is rarely without a 2-mm crust of some kind.

Grain-Size Determinations: The melt crusts also affect grain size in the underlying snow layers. Examination of older layers reveals considerably greater grain size than in the newer layers.

This grain-size phenomenon, and its manifestations in ramsonde (the ramsonde measures snow hardness) and density tests, is the only stratigraphic indicator found thus far in the snow pits of the high plateau.

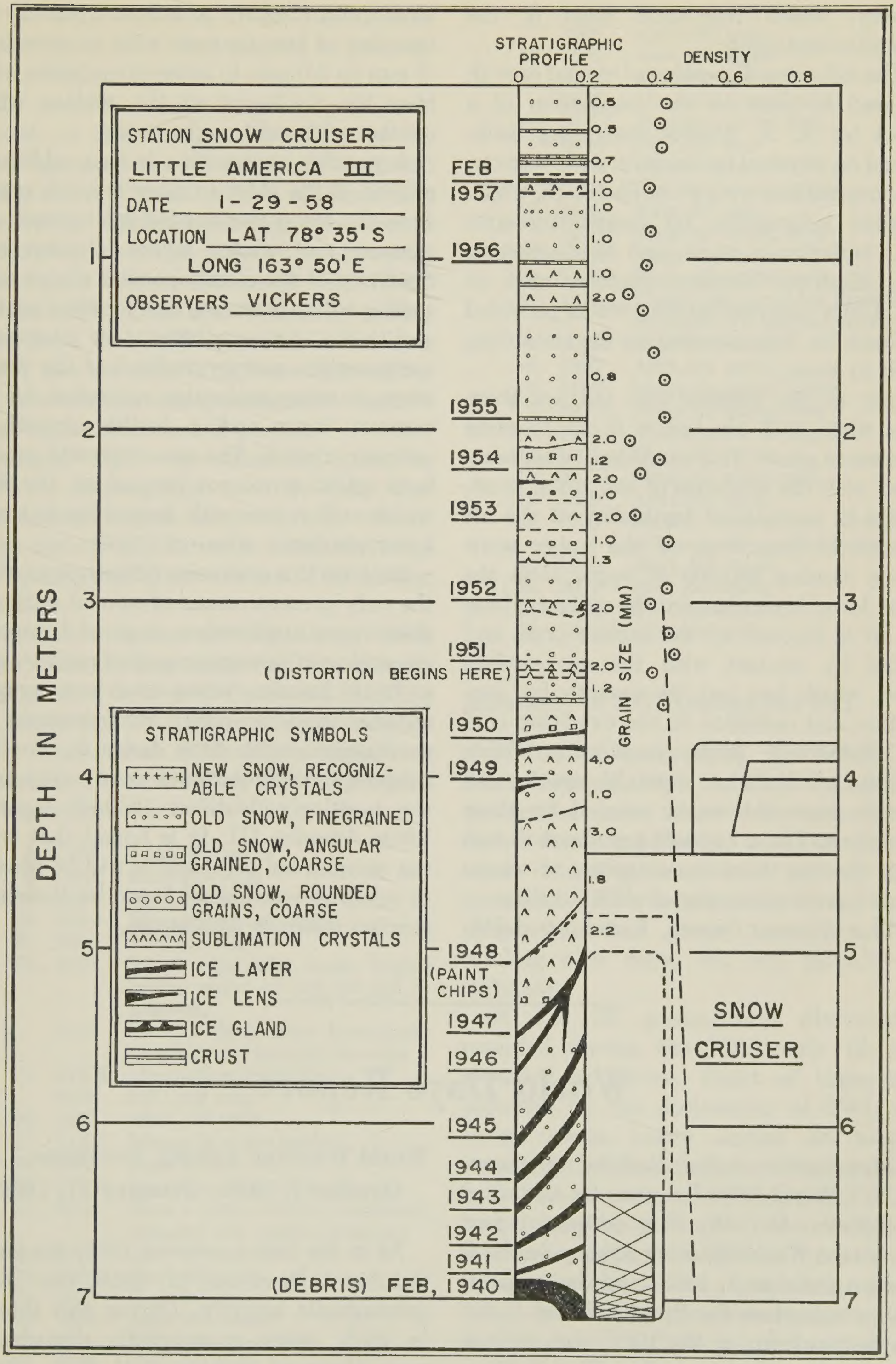

Fig. 4. *Profile of Snow Stratigraphy at Little America III. Snow cruiser and debris at 1940 level provide a benchmark to check stratigraphic interpretations. Distortion below 3.4-m level resulted from unnatural melting caused by presence of snow cruiser. Circled dots represent measured snow densities, keyed to scale at top right; dashed line projects density profile downward.*

country, which represents most of the Antarctic continent.

(The following discussion of crystal growth is based in part on the translation of a report by A. A. Shakov providing background on physical processes in a snow cover, on conversations with P. A. Shumskii, which supplied information on temperature-gradient variation in snow, and on discussions with Herfried Hoinkes, meteorologist at IGY Little America Station, which provided the basis for the reasoning on the instability of air in snow.)

Only in the summer and fall are there days when cold air occurs in conjunction with warm snow. This condition, when combined with the existence of the 2-mm crust, results in mechanical instability of the air trapped in interstices of the upper snow layers, causing transfer of vapor from the warm lower layers toward the surface. Here, the air is blocked by the surface crust and chilled by contact with the near-surface snow, which has lost its warmth by conduction and radiation to the overlying cold air. Relatively large, readily-identifiable crystals (sublimation crystals) are formed directly from the vapor created by these conditions. These crystals are about .8 mm long, whereas those characteristic of winter layers have a grain size of about .3 mm.

Older summer layers, found at depth, have grain sizes up to 5.0 mm, raising the question of how they are able to grow from .8 mm to 5.0 mm in subsequent years when they are no longer at the surface where contact with cold might occur.

A possible explanation is that additional growth of the older summer crystals results from the temperature gradient between the summer and winter layers. Greater conductivity of the closely-packed winter snow (owing to the increased surface-area contact and to the smaller volume of air interstices) increases the energy gradient of the winter snow, causing molecular migration to the summer layer and a further growth of summer crystals. The second growth process is in addition to, not instead of, the first, which still occurs with instability but with lesser gradients when at depth.

Because this grain-size difference provides the only present means of annual dating of snow strata applicable to most of Antarctica (apart from the warmer coastal regions, such as Little America, where other stratigraphic criteria may be used) reinforcement by geochemical methods is desirable. For this purpose, tritium samples were taken from the positively-identified 1939–40 layer at Little America III. It is hoped that when the samples are processed it will be possible to reinforce conclusions based on the stratigraphic methods now in use.

World Days Report

References to earlier *Bulletin* reports on the IGY World Days Program are contained in *Bulletin No. 19*. The present report reviews the World Warning Agency decisions between October 1, 1958, and January 31, 1959, summarizes the Special World Intervals declared during the IGY, and outlines a successor program, the World Days Program for the International Geophysical Cooperation—1959.

World Warning Agency Decisions, October 1, 1958—January 31, 1959

As in the last quarter of 1957, the period October 1–December 31, 1958, was low in geomagnetic activity. During this interval in 1958, seven geomagnetic disturbances were observed, only one of them severe. November 1958, only the second month during the IGY in which no geomagnetic

storms were recorded, was the quietest month of the IGY with respect to geomagnetic activity.

Six periods of Alert were declared, two in each of the three months. Five of the seven geomagnetic disturbances occurred during three of these periods of Alert. The three other Alerts, including the two in November, were not followed by geomagnetic storms. There were three Special World Intervals (SWI), one in each month, totaling seven days. One SWI was not followed by a storm, but the other two were followed by the two most severe geomagnetic disturbances of the three-month period.

January 1959 was relatively quiet in terms of geomagnetic activity. Only two geomagnetic storms occurred, both minor. Three periods of Alert were declared during the month, and there was one SWI lasting two days.

The following is a list of Alerts, SWI, major flares, and geomagnetic disturbances for the period October 1–December 31, 1958; the Alerts and SWI are numbered consecutively from Alert #34, which ended on September 18, and SWI #18, which ended on August 28:

Oct	3	1600	Alert #35 starts
	6	1600	Alert #35 ends
	14	1600	Alert #36 starts
	22	0315	Magnetic storm begins
	23	0001	SWI #19 starts
	24	0730	Severe magnetic storm begins (while storm of Oct. 22 still in progress)
		1410	Class 3 flare; slow ionospheric drop-out and gradual recovery
	25	01XX	Magnetic storm ends
		2359	SWI #19 ends
	26	1600	Alert #36 ends
	27	15XX	Magnetic storm begins
	28	1505	Class 3 flare
	29	04XX	Magnetic storm ends
	31	0950	Class 3 flare; sudden ionospheric drop-out and gradual recovery
Nov	14	1600	Alert #37 starts
	16	1600	Alert #37 ends
	24	1607	Class 3 flare
	25	1600	Alert #38 starts
	26	0001	SWI #20 starts
	27	2359	SWI #20 ends
	30	1600	Alert #38 ends
Dec	4	0035	Magnetic storm begins
		1600	Alert #39 starts
	5	04XX	Magnetic storm ends
	7	1600	Alert #39 ends
	10	1600	Alert #40 starts
	13	0001	SWI #21 starts
		0002	Magnetic storm begins
	14	06XX	Magnetic storm ends
		2359	SWI #21 ends
	15	1120	Class 3 flare
		2022	Magnetic storm begins
	16	1600	Alert #40 ends
		21XX	Magnetic storm ends
	17	1820	Magnetic storm begins
	18	14XX	Magnetic storm ends
	31	1656	Class 3 flare; sudden ionospheric drop-out and gradual recovery
Jan	1	1600	Alert #41 starts
	3	1600	Alert #41 ends
	5	0136	Magnetic storm begins
	7	09XX	Magnetic storm ends
	9	1459	Magnetic storm begins
	10	1600	Alert #42 starts
	11	02XX	Magnetic storm ends
	14	1600	Alert #42 ends
	21	1700	Class 3 flare; sudden ionospheric drop-out and gradual recovery
	22	1600	Alert #43 starts
	24	0001	SWI #22 starts
	25	2359	SWI #22 ends
	29	1600	Alert #43 ends

Summary of SWI During the IGY

SWI were declared by AGIWARN 22 times during the IGY, totaling 47 days. The declarations were followed by geomagnetic disturbances in 16 cases, with two disturbances occurring in each of two of these cases. One SWI was initiated after a geomagnetic storm had started, and five SWI, totaling nine days, did not include disturbances.

Of the 55 geomagnetic disturbances recorded during the IGY, only 15 were classified as severe. Eight of these were preceded by the declaration of SWI. One severe storm began during an already successful Interval (one for which geomagnetic and other associated terrestrial effects had already been recorded) and another, in September 1957, was missed intentionally because several severe storms had already been successfully predicted during the month and it had been previously agreed to limit the number of SWI called in any month. In the remaining five cases, storms were missed because the solar events did

not suggest storms of great magnitude. One of these, unfortunately, was among the most severe storms observed during the IGY.

During six of the 18 months of the IGY (July and November 1957, and July, August, October, and September 1958) SWI were declared prior to the onset of the most severe disturbance of the month. In August 1957 and in March and June 1958 the initiation of Intervals preceded the month's second most severe disturbance. No geomagnetic storms were recorded in January and November 1958, and only one minor storm was observed in each of October and December 1957 and in April 1958.

World Days Program for IGC-1959

A program for World Days, Alerts, and Special World Intervals during the International Geophysical Cooperation—1959 has been put into effect. It represents a modification and simplification of the program carried out during the IGY. Figure 5 is the final calendar of World Days for IGC-1959.

Under IGY, the only kind of Alert was a world-wide one, declared when high solar activity indicated the probability of significant geophysical effects. The IGC plan, on the other hand, calls for regional Advance Alerts after the beginning of outstanding geophysical events; on the basis of these, the World Warning Agency (AGIWARN), operated by the National Bureau of Standards at Fort Belvoir, Va., then decides whether to declare a world-wide Alert or Special World Interval.

Regional Advance Alerts: Provision is made in the IGC World Days Program for four kinds of regional Advance Alerts—Solar Flare, Magnetic Storm, Cosmic Ray Increase or Decrease, and Auroral. The Advance Alerts are issued at any time of the day as soon as possible after the beginning of one of these geophysical events meeting the established criteria, as follows:

Solar Flare—Issued whenever a solar flare of median importance (2+) or greater has been reported.

Magnetic Storm—Whenever a significant magnetic storm, K-index of 5 or greater at a middle latitude station, has begun. (The K-index expresses geomagnetic activity in terms of a scale ranging from 0, or very quiet, to 9, or extremely disturbed.)

Cosmic Ray—Whenever an outstanding increase or decrease in cosmic ray flux has been observed.

Auroral—Whenever a magnetic storm in middle latitudes has reached a K-index of 7 or whenever selected auroral stations report the presence of an outstanding aurora.

Each Regional Warning Center (RWC) may issue an Advance Alert within its region as soon as the phenomenon is recognized and the RWC is satisfied it meets the established criteria. The Advance Alert is issued by telegram in a standard text form. It is distributed promptly within the originating region and is also sent promptly to other RWCs for distribution, if practical and expedient, within their respective regions. The Advance Alert messages serve both as an aid in the observing programs of individual stations within the regions and as advice to the World Warning Agency on the declaration of world-wide Alerts and SWI.

The text for Advance Alert messages includes the reporting station, the type of event, and the date and time of the event. The following are some sample Advance Alert messages:

(a) ADVANCE GEOPHYSICAL ALERT KOKOBUNJI SOLAR FLARE 280010Z.
(This means a solar flare of importance 2+ or greater was observed on 28th day of month at 0010 UT by Kokobunji.)

(b) ADVANCE GEOPHYSICAL ALERT NIZMIR MAGNETIC STORM 291900Z.
(This means NIZMIR recorded beginning of significant magnetic storm, K-index of at least 5, on 29th day at 1900 UT.)

(c) ADVANCE GEOPHYSICAL ALERT ZUGSPITZE COSMIC RAY DECREASE 061130Z.
(This means the nominal time of an unusual cosmic ray flux decrease was 6th day at 1130 UT at Zugspitze.)

(d) ADVANCE GEOPHYSICAL ALERT CORNELL AURORA OBSERVED 070230Z.
(This means outstanding aurora observed 7th

International Geophysical Cooperation 1959
Final Calendar

1959 JANUARY 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

1959 FEBRUARY 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri	Sat.
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

1959 MARCH 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

1959 APRIL 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

1959 MAY 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24/31	25	26	27	28	29	30

1959 JUNE 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

1959 JULY 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

1959 AUGUST 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23/30	24/31	25	26	27	28	29

1959 SEPTEMBER 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

1959 OCTOBER 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

1959 NOVEMBER 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

1959 DECEMBER 1959

Sun.	Mon.	Tue.	Wed.	Thu	Fri.	Sat.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

1960 JANUARY 1960

Sun.	Mon.	Tue.	Wed.	Thu.	Fri.	Sat.
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24/31	25	26	27	28	29	30

3 Regular World Day

18 Regular World Day with highest priority

9 Regular World Day with unusual meteoric activity

10 Regular World Day with highest priority and unusual meteoric activity

2 Day of total eclipse

17 18 19 20 21 / 22 23 24 25 26 Regular World Interval (RWI)

16 17 18 / 19 20 21 22 23 24 25 World Meteorological Interval (WMI)

Fig. 5. *Final World Days Calendar for IGC-1959.*

day at 0230 UT at Cornell University, Ithaca, N. Y.)

(e) ADVANCE GEOPHYSICAL ALERT AGIWARN AURORAL-INFERRED MAGNETIC STORM 070230Z.
(This means beginning of significant magnetic storm, K-index of 7 or greater, recorded 7th day 0230 UT AGIWARN. Auroral displays should be expected.)

World-Wide Alerts and SWI: On the basis of these Advance Alerts from Regional Warning Centers, the World Warning Agency decides whether to declare a world-wide Alert in one or more of the following categories: Magnetic Storm, Cosmic Ray Increase, Aurora. (Solar Flare and Cosmic Ray Decrease Alerts are only distributed regionally.) It may simultaneously declare an SWI, during which laboratories and stations intensify their observations.

World-wide Alerts and SWI are declared by a Warning Message issued by AGIWARN at 1600 UT (Universal Time, same as Greenwich Civil Time) on any day when geophysical phenomena in the preceding 24 hours meet the stated criteria. On other days, no Warning Message is issued (although a dummy message may be circulated over some distribution networks for a daily check of communications). The world-wide Alert messages issued by AGIWARN are in standard texts similar to those of the Advance Alerts but bear a serial number and, when appropriate, the time and date of the beginning or ending of an SWI or instructions to continue one.

Warning Messages are broadcast by the National Bureau of Standards radio station WWV (Washington, D. C.), by WWVH (Hawaii), and by certain other standard-frequency broadcast stations. A symbol in Morse Code indicates the "State of Warning" at the time of each broadcast. This symbol is sent very slowly so that it may be recognized by scientists who are not specialists in radio-telegraphy.

Since time must be allowed for the Warning Message to reach the broadcast station, the "First Broadcast" to take into account a Warning Message will be made by WWV, at 1604 and repeated twice hourly at 04 and 34 min after the hour. WWVH's First Broadcast will be at 1714 and its repeat broadcasts will come at 14 and 44 min after the hour.

The following are the State of Warning symbols used in Warning Messages announcing world-wide Alerts:

a) AGI-AAAAA	An Alert was declared at 1600 UT (type not specified)
b) AGI-(Three extra long dashes)	SWI in progress
c) AGI-EEEEE	No Alert declared at 1600 UT

The symbols broadcast as a consequence of each variety of Warning Message are given below (the introductory parts of text and symbol have been omitted in this table).

Warning Message Text	State of Warning Symbol	Remarks
a) Magnetic Storm (time*)	AAAAA	broadcast for 24 hrs. only
b) Aurora (time*)	AAAAA	broadcast for 24 hrs. only
c) Cosmic Ray Increase (time*)	AAAAA	broadcast for 24 hrs. only
d) [Alert message as in (a), (b) or (c)] plus Start Special World Interval	(Three extra long dashes)	

* Time (UT) of onset of phenomenon.

IGY Bibliographic Notes

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